IOP Conf. Series: Materials Science and Engineering **323** (2018) 012016 doi:10.1088/1757-899X/323/1/012016

Operation of single-bucket excavator transmission system

Olga Lukashuk[1], A P Komissarov[1,2] and K Yu Letnev[1]

[1]Ural Federal University, 620002, 19 Mira Street, Yekaterinburg, Russia
[2]Ural State Mining University, 620014, 85 Khokhryakova Street, Yekaterinburg, Russia

*E-mail: oldim96@mail.ru

Abstract.The goal of the research was to determine the mechanism behind formation of operation parameters for the main mechanisms of a single-bucket excavator. It was established that when the main mechanisms of the excavator (hoisting and thrusting mechanisms) and the mechanism of its operational equipment (all of them being parts of its transmission system) act jointly, the modes of hoisting and thrust mechanisms operation change significantly. Operation parameters of the excavator's main mechanisms (hoisting and thrusting velocity and forces) were evaluated from the positions of its bucket in the work area.

1. Introduction

For a single-bucket excavator as a complex electromechanical system, the efficiency of its operation are determined by the degree of correspondence between operation parameters of its main mechanisms (hoisting and thrusting mechanisms) and coordination between them during the operation which is carried out by the excavator's end effector in accordance with the law of its motion.

The scientific basis and main principles behind efficient operation of hydraulic excavators (as the main type of excavation machinery) were developed and formulated in the papers authored by Melnikov N. N., Ranev A. V., Steinzeig V. M. and other scientists. Further development of the theory of hydraulic excavators could be found in [1-8].

The law of bucket motion (path, rock resistance to excavation) depends on mining and technical conditions of operation (rock density, presence of oversize blocks, height of a working face slope and so on). A change in the conditions leads to a significant scatter in the values of operation parameters and hinders the process of rock excavation.

Determining the mechanism behind formation of those values for various conditions of operation would allow to validate the selection of an efficient control algorithm for the working procedure and use full capacity of a single-bucket excavator's power unit.

2. The Solution of the Tasks

The goal of the research is to determine the mechanism behind formation of operation parameters for the main mechanisms of a single-bucket excavator (that is the capacity used in the process of excavation).

The tasks of the research are:

- to evaluate the operation parameters of the main mechanisms from the positions of the excavator's bucket in the work area;
- to determine the degree of interaction between the main mechanisms in their joint action.

3. The Goal of the Research and its Tasks

One special feature of the electromechanical system of a single-bucket excavator (figure 1) is its two-stage transmission gear, which consists of the excavator's main mechanisms (hoisting and thrusting mechanisms) and the mechanism of its operational equipment (connecting the main mechanisms and its end effector (the bucket)).

The operational equipment mechanism (figure 2) includes four movable links: link *1* in the form of rigidly connected stick *AB* and bucket *BK* ("stick-bucket link"), which forms a two-degrees-of-freedom kinematic pair (translational and rotational freedoms) with stand O_1 via a saddle bearing – link *2*; link *3* – an element of the hoisting rope and link *4* – lead block of the boom. Links *3* and *4* are kinematically equivalent to the rods which form rotational pairs with each other, link *1* and stand O_2. Links *2* and *4* are output links of the thrusting and hoisting mechanisms. And then, the velocity of point *A*, which is the same for links *1* and *2*, is equal to the velocity of thrust V_T, and the velocity of point *D* – equal to the velocity of hoisting V_H.

That mechanism has two degrees of freedom, that is the number of possible independent motions (generalized coordinates) equals two. The coordinates could be established in the positions of the links *2* and *4* or – as the link *1* forms a two-degrees-of-freedom kinematic pair with the stand – in the position of the link *1*. Since the positions of the links *2* and *4* are arbitrary due to uncoordinated functioning of the hoisting and thrusting mechanisms, then the coordinates of point *K* (the end of the link *1* and the top of the cutting edge of the bucket or its teeth) in the fixed coordinate system *X*-*Y* and the inclination of the point *K* path of motion (direction of the excavation velocity) are taken as the generalized coordinates.

The fixed coordinate system consists of two mutually perpendicular axes which intersect in point *O* (*OX* – the datum level of the excavator, *OY* – the rotation axis of its platform). Since the position of the bucket determines the positions of all links of its mechanisms, then the link *1* could be taken as the initial link. Which means, to determine the positions and velocities of the links in the mechanism of operational equipment and the values of operation parameters for the main mechanisms, one should start by determining (setting) the positions and velocity of the link *1* (the top of the cutting edge).

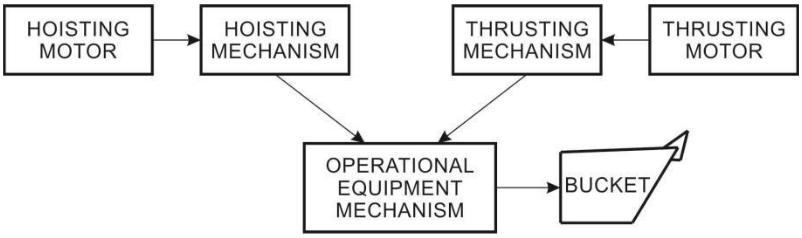

Figure 1. Structural diagram for the electromechanical system (excavation mechanisms) of a single-bucket excavator.

On the basis of the mathematical model which was established for the mechanism of operational equipment, the relations for determining the operation parameters of the hoisting and thrusting mechanisms (velocities of hoisting VH and thrusting V_T, forces of hoisting F_H and thrusting F_T) were obtained.

Table 1 shows the results of a computing experiment carried out in order to calculate the operation parameters for the main mechanisms of an EKG-20 excavator made by JSC «Uralmashplant».

The initial data for the calculation are:

- size of the excavator's work area (figure 3);
- paths of its bucket's motion (the top of the cutting edge – point *K*) as direct lines which follow the edges and the centre of the work area at the angle equal to the inclination of a face slope;
- velocity of excavation V_E = 1 m/s;
- rock resistance to excavation (tangent line) F_R^{τ} = 325 kN; gravity force of an empty bucket G_B = 400 kN; gravity force of a loaded bucket (bucket and rock) G_{B+R} = 700 kN and gravity force of the stick G_S = 300 kN.

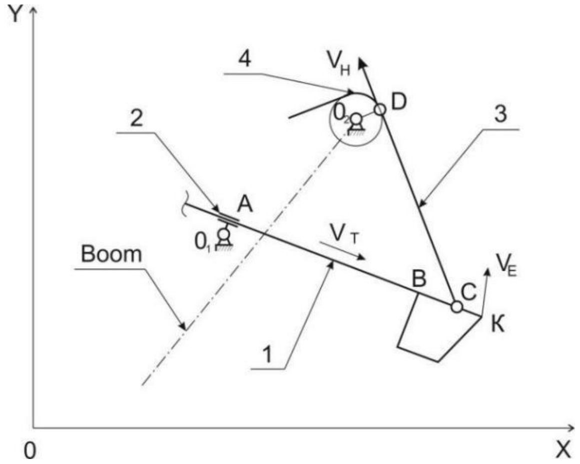

Figure 2. Schematics of the operational equipment mechanism: 1 – "stick-bucket" link; 2 – saddle bearing; 3 – segment of the hoisting rope; 4 – lead block; O_1, O_2 – stands; OX – datum level of the excavator; OY – rotation axis of its platform; V_H – velocity of hoisting; V_T – velocity of thrusting; V_E – velocity of excavation.

Table 1. The operation parameters for the main mechanisms of an EKG-20 excavator.

№	Initial data		Calculated data				
	X_K, m	Y_K, m	G_{B+R}, kN	V_H, m/s	V_T, m/s	F_H, kN	F_T, kN
				Initial path of motion (A)			
1	9	0	400	0.95	– 0.87	290	– 630
2	10.15	2	435	0.92	– 0.81	350	– 620
3	11.3	4	470	0.84	– 0.70	420	– 605
4	12.45	6	500	0.70	– 0.51	520	– 580
5	13.6	8	540	0.52	– 0.19	700	– 555
6	14.75	10	575	0.50	0.19	975	– 590
7	15.9	12	610	0.66	0.50	1270	– 700
8	17.05	14	650	0.80	0.70	1560	– 850
9	18.2	16	680	0.89	0.81	1810	– 1005
10	18.8	17	700	0.91	0.84	1910	– 1060
				Intermediate path of motion (B)			
11	13.5	0	400	0.88	– 0.64	610	– 310
12	14.65	2	435	0.83	– 0.51	640	– 300
13	15.8	4	470	0.76	– 0.34	680	– 280
14	16.95	6	500	0.70	– 0.12	710	– 230
15	18.1	8	540	0.66	0.11	780	– 155
16	19.25	10	575	0.65	0.32	830	– 40
17	20.4	12	610	0.62	0.50	885	140
18	21.55	14	650	0.50	0.63	930	420
19	22.7	16	680	0.22	0.72	1015	845
20	23.3	17	700	0.02	0.76	1125	1130
				Terminal path of motion (C)			
21	18	0	400	0.79	– 0.39	1020	110
22	19.15	2	450	0.73	– 0.25	1060	150
23	20.3	4	500	0.68	– 0.09	1100	210
24	21.45	6	550	0.61	0.07	1150	320
25	22.6	8	600	0.53	0.23	1210	480
26	23.75	10	650	0.42	0.38	1290	710
27	24.9	12	700	0.27	0.50	1420	1030

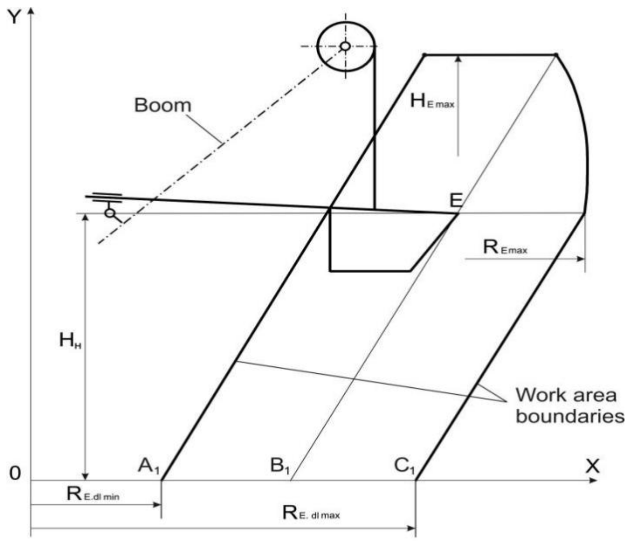

Figure 3. EKG-20 work area: *A*, *B*, *C* – paths of bucket motion; $H_{E.max}$, $H_{E.calc}$ – maximum and calculated heights of excavation; H_T – height of thrusting shaft axis; $R_{E.dl.min}$, $R_{E.dl.max}$ – minimum and maximum radiuses of excavation at the datum level of the excavator; $R_{E.max}$ – maximum radius of excavation.

The table demonstrates that the operating modes of the motors and the operation parameters of the main mechanisms change significantly within the excavator's work area depending on the position of its bucket. For example, when excavation is carried out in the bottom section of the work area at $Y_K \leq 6$, the motor of the hoisting mechanism is operating in traction mode, and the motor of the thrusting mechanism – both in traction mode with reverse rotation for the bucket following the paths *A* and *B* and in opposed action mode (braking – directions of F_T and V_T are opposite) for the bucket following the path *C* (figure 4).

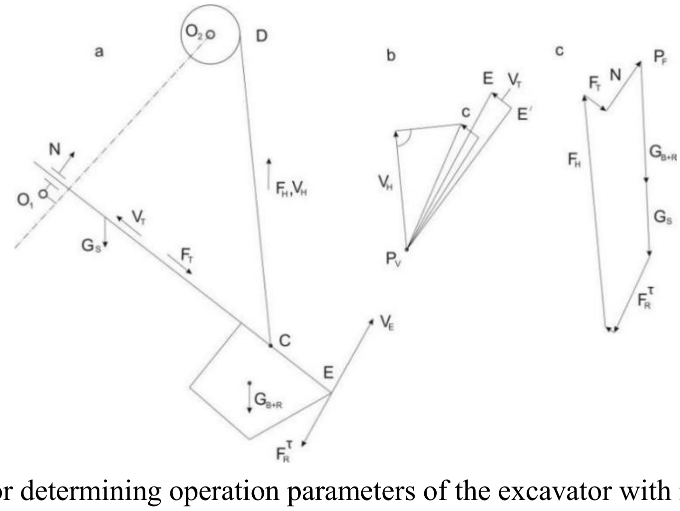

Figure 4. Diagram for determining operation parameters of the excavator with its bucket positioned in the bottom section of the work area (paths *C*): a – vector diagram of the mechanism, b – vector diagram of velocities, c – vector diagram of forces.

When excavation is carried out in the middle section of the work area at $6 \leq Y_K \leq 12$ m, the motor of the hoisting mechanism is operating in traction mode, and the motor of the thrusting mechanism – in three modes: traction mode with reverse rotation, dynamic braking mode for $F_T < 0$ (figure 5) and traction mode for the bucket following the path *C* (figure 6).

When excavation is carried out in the top section of the work area at $12 \leq Y_K \leq 17$ m, the motor of the hoisting mechanism is operating in traction mode, and the motor of the thrusting mechanism –

both in dynamic braking mode for the bucket following the path *A* and in traction mode for the bucket following the intermediate path *B*.

The operation parameters of the main mechanisms change in accordance with the operating modes of their motors and vary within a wide range [9] .

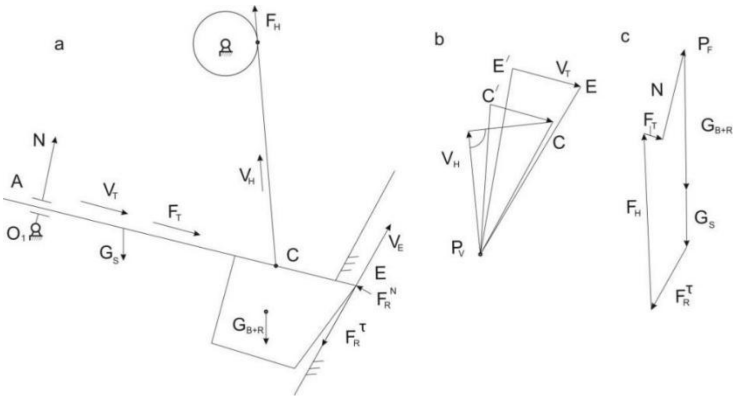

Figure 5. Diagram for determining operation parameters of the excavator with its bucket positioned in the middle section of the work area.

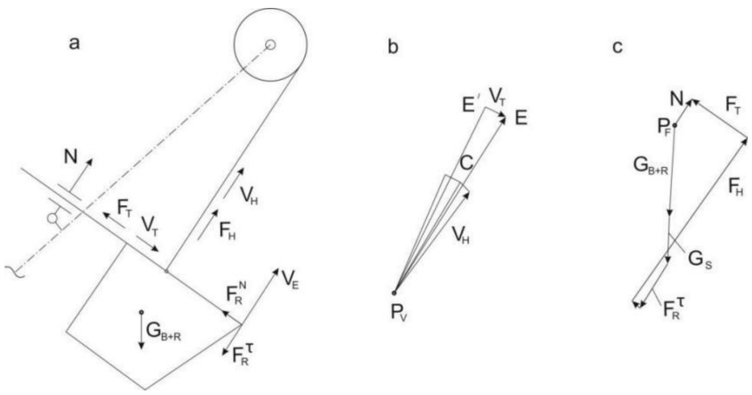

Figure 6. Diagram for determining operation parameters of the excavator with its bucket positioned in the middle section of the work area (path *A*).

The velocities of operating motions depend on the positions of the bucket in the work area (particularly, on the coordinate Y_K). With the exception of the bucket following its initial path (figure 7), the velocity of hoisting decreases with an increase in the height of excavation (Y_K), and the velocity of thrusting decreases for lower heights of excavation and increases with an increase of the height. The maximum values of those velocities are close to the velocity of excavation: $V_{H.max}$ = 0.95 m/s и $V_{T.max}$ = 0.84 m/s (for the initial path of motion).

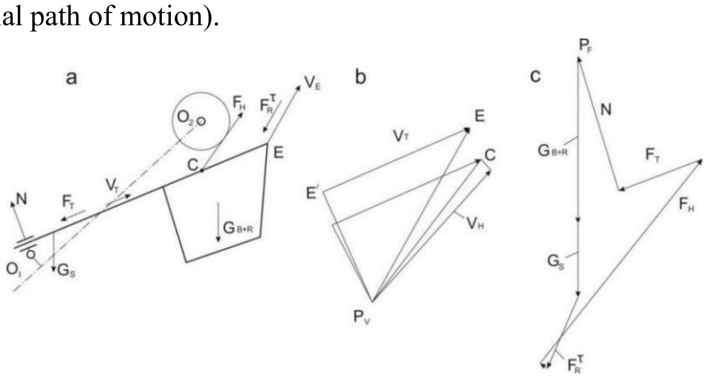

Figure 7. Diagram for determining operation parameters of the excavator with its bucket positioned in the top section of the work area (path A).

The forces of hoisting and thrusting increase with an increase in the height of excavation (with the exception of thrusting forces for the bucket following the intermediate path B). The maximum values of those forces are $F_{H.max}$ = 2.05 MN and $F_{T.max}$ = 1.26 MN. The maximum values referred in the specification for the excavator are considerably smaller. For instance, the value of the maximal hoisting force [10] – which determines the braking torque of the hoisting mechanism motor – $F_{H.max}$ = (1.25…1.43)$F_{H.calc}$ = 1350…1540 kN ($F_{H.calc}$ = 1080 kN is the force of hoisting with the height of excavation equal to the height of the thrusting shaft axis for the bucket following the intermediate path).

The increase in the forces of hoisting and thrusting with an increase in the height of excavation is caused by counteraction of the hoisting and thrusting motors (differently directed forces of hoisting and thrusting). In that case, the moment of forces which tilts the boom towards the excavator increases, which can lead to the boom swinging (jacking [11]) and, subsequently, returning (falling) into its initial position (which is accompanied by considerable dynamic loads).

4. Conclusion

In the process of excavation, the operating modes of the hoisting and thrusting motors and the operation parameters (velocity and forces) of the mechanisms change considerably depending on the position of the bucket in the excavator's work area.

In that case, controlling the process and maintaining the paths of motion which should be followed by the bucket and which correspond to the inclination of a face slope (rockfall) is quite a difficult task to handle by means of current tools (joysticks).

References

[1] Borshh-Komponiec L. V. Methodology of prompt assessment for open-pit hydraulic excavators // Mining industry. 1996. № **1**. pp. 29-37.

[2] Komissarov A. P., Lautenshlejger A. A., Suslov N. M. Assessment of energy parameters of hydraulic-excavator operational equipment // Heavy engineering industry. 1991. № **8**. pp. 25-29.

[3] Bules P. Operating efficiency of open-pit excavators with electromechanical and hydraulic drives for main mechanisms // Mining industry. 2014. № **6** (118). pp. 36-37.

[4] Visbek Z. et al. On efficiency of using open-pit hydraulic excavators // Mining industry. 1998. № **5**. pp. 25-29.

[5] Dudczak A. Excavators: theory and design. Warsaw: PWN, 2000.

[6] Geu Flores F., Kecskemethy A., Pottker A. Workspace analysis and maximal force calculation of a face-shovel excavator using kinematical transformers. 12th IFToMM World Congress, Besancon, June 18-21, 2007. 6 p.

[7] Frimpong S., Hu Y., Chang Z. Perfomance simulation of shovel excavators for earthmoving operations // In Summer in computer simulation conference (SCSC'03). 2003. pp. 133-38.

[8] Park B. Development of a virtual reality excavator simulator: a mathematical model of excavator digging and a calculation methodology. PhD Diss. Virginia Polytechnic Institute and State University. Blackburg, Virginia, USA, 2002. 223 p.

[9] Epifanov A. P., Malajchuk L. M., Gushhinskij A. G. Electric drive. Saint Petersburg: Lan, 2012. 400 p.

[10] Beljakov Yu. I. Planning excavation procedures. Moscow: Nedra, 1983.

[11] Podjerni R. Yu. Machinery of mines. Moscow: MGGU, 2007. 680 p.